USU Gauss-Markov Model: High Resolution Regional Capability and Support for AFWA

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LONG-TERM GOALS

Our primary goal is to support the Air Force Weather Agency (AFWA) during the implementation of our Gauss-Markov Kalman Filter (GMKF) model for DoD applications. A secondary goal is begin the development of a high-resolution regional capability.

OBJECTIVES

In an operational setting, the Gauss-Markov Kalman Filter model runs continuously and reconstructs the global electron density distribution as a function of time. The model automatically acquires the relevant data on the web, quality controls the data, inputs the data into the Kalman filter, and outputs a variety of ionospheric parameters at a 15-minute cadence. The data assimilated can include slant TEC from up to 1000 ground GPS receivers, bottom-side electron density profiles from 20 digisondes, in situ electron densities from several DMSP satellites, and integrated UV emissions from satellites. In practice, however, different amounts of data are assimilated, depending on the data availability. Therefore, one of our objectives is to determine what effect each data type has on the Kalman filter reconstruction. Another objective is to determine how much data are needed in a regional run of the Gauss-Markov model in order to achieve a desired accuracy. A third objective is to support Northrop Grumman, the Naval Research Laboratory (NRL), the Air Force Research Laboratory (AFRL), and AFWA in their validation and implementation efforts.

APPROACH

Gauss-Markov and Full Physics Kalman Filter models were developed at USU as part of a DoD Multidisciplinary University Research Initiative (MURI) program and the USU effort was called Global Assimilation of Ionospheric Measurements (GAIM). The Gauss-Markov Kalman Filter (GMKF) model is based on the Ionosphere Forecast Model (IFM; *Schunk et al., 1997*), which covers the E-region, F-region, and topside ionosphere up to 1400 km, and takes account of six ion species (NO^+, O_2^+, N_2^+, O^+, He^+, H^+). However, the output of the model is a 3-dimensional electron density distribution at user specified times. In addition, auxiliary parameters are also provided, including *NmF2, hmF2, NmE, hmE*, slant and vertical TEC. In the Gauss-Markov Kalman Filter, the ionospheric densities obtained from the IFM constitute the background ionospheric density field on which perturbations are superimposed based on the available data and their errors. To reduce the computational requirements, these perturbations and the associated errors evolve over time with a

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statistical model (Gauss-Markov process) and not, as in the case of a Full-Physics-Based Model, rigorously with the physical model. As a result, the Gauss-Markov Kalman filter can be executed on a single CPU workstation. Like all assimilation techniques, the Gauss-Markov Kalman filter uses the errors on the observations and model in the analysis, and computes the errors in the match. The Gauss-Markov Kalman filter model is a global model that can support regional assimilation windows within the model specification (*Schunk et al.,* 2004a,b; *Scherliess et al.,* 2004,2005). This Gauss-Markov Kalman Filter model is used to accomplish the goals and objectives outlined above.

WORK COMPLETED

We have provided implementation support for Northrop Grumman, AFRL, NRL, and AFWA, and we have addressed important issues concerning the development of a high-resolution regional capability for our Gauss-Markov model. The details are as follows:

(1) We upgraded and documented the Gauss-Markov model's regional capability.

(2) We upgraded the source code to support compilation on Sun/Solaris so that the model could be compiled at AFWA without modification.

(3) We provided an algorithm to convert the GAIM output format to the PRISM format.

(4) We helped Northrop Grumman debug a model crash – it was due to the corruption of the 30 gigabyte Gauss-Markov database during the transfer to the Sun computer.

(5) We helped Northrop Grumman identify a problem with ionosonde-data handling scripts – the data from a single station was mistakenly used for all the stations around the globe.

(6) We expanded the capabilities of the data-reading interface to accept the unexpected time stamps of JPL TEC data.

(7) We performed a study of the model to determine the best way to handle the JPL data – these data already had the satellite and ground station biases removed. In the mixed JPL and RINEX data environment, the bias calculations must still be performed for the RINEX data, but not for the JPL-provided data. A data handling procedure was developed.

(8) We helped Northrop Grumman with the implementation of the run-time scripts for using the Ionosphere Forecast Model. The IFM must be run repeatedly, as better numbers for Kp, F10.7 become available, and must be run ahead of the Gauss-Markov model so that the Gauss-Markov model does not sit and wait for the IFM output.

(9) We supported several teleconferences, which were held every other week.

(10) We worked with Northrop Grumman on procedures for using the model's hot start capability.

(11) We validated the effectiveness of changes to the model to support previously listed tasks.

(12) We delivered upgraded versions of the model to Northrop Grumman, AFWA, NRL and AFRL.

RESULTS

Both the Gauss-Markov (GM) data assimilation model and the background Ionosphere Forecast Model (IFM) were validated using measurements from 11 ionosonde stations that are associated with the Australian Department of Defense sounder network (*Sojka et al., 2006*). The ionosondes provide bottomside electron density profiles that can be compared to those calculated by the two models. The comparisons involved both monthly mean climatology and day-to-day weather for a 31-day period (20 March – 19 April, 2004). A skill score was developed for the day-to-day weather by using the International Reference Ionosphere (IRI) as a reference model. The results of the study are as follows: (1) The IFM (the background physics-based model), the Gauss-Markov data assimilation model, and the IRI all had a similar foF2 climatology for the 31-day period; (2) The background IFM, by itself, was slightly better than the IRI in specifying weather; (3) Overall, the GM data assimilation model did much better than both the IFM and IRI in describing ionospheric weather; and (4) The GM data assimilation model had some difficulty in describing the increase in ionization at sunrise. The GM model is currently being modified to correct this latter problem.

IMPACT/APPLICATIONS

The USU Gauss-Markov and Full Physics Kalman Filter models provide ionospheric specifications and forecasts on both global and regional grids. These specifications and forecasts are useful for DoD and civilian systems and operations, including HF communications and geo-locations, over-the-horizon (OTH) radars, surveillance, and navigation systems that use GPS signals.

TRANSITIONS

Operational Version 2.2 of the Gauss-Markov model was delivered to the Naval Research Laboratory (NRL) and the Air Force Weather Agency (AFWA) on January 15, 2005, and Operational Version 2.3 was delivered to NRL, AFRL, AFWA, and the Community Coordinated Modeling Center (CCMC) on July 15, 2005.

RELATED PROJECTS

This project resulted from a basic research MURI program called Global Assimilation of Ionospheric Measurements (GAIM). A research grade version of our Gauss-Markov Kalman Filter model was developed under the MURI program.

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